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GHG avoided emissions and economic analysis by power generation potential in posture aviaries in Brazil

Eruin Martuscelli Ribeiro [a], Regina Mambeli Barros [b, *], Geraldo Lúcio Tiago Filho [b], Ivan Felipe Silva dos Santos [a], Luma Canobre Sampaio [c], Ticiane Vasco dos Santos [c], Fernando das Graças Braga da Silva [b], Ana Paula Moni Silva [d], João Victor Rocha de Freitas [a]

[a] Federal University of Itajubá, (Engenharia da Energia da Universidade Federal de Itajubá), Av. BPS, 1303, Itajubá-MG, CEP: 37500-903, Brazil
[b] Federal University of Itajubá, National Reference Center in Small Hydropower, (Instituto de Recursos Naturais da Universidade Federal de Itajubá, Centro Nacional de Referência em Pequenas Centrais Hidrelétricas), Av. BPS, 1303, Itajubá-MG, CEP: 37500-903, Brazil
[c] Federal University of Itajubá, (Engenharia Ambiental da Universidade Federal de Itajubá), Av. BPS, 1303, Itajubá-MG, CEP: 37500-903, Brazil
[d] Federal University of Itajubá (Instituto de Recursos Naturais da Universidade Federal de Itajubá), Av. BPS, 1303, Itajubá-MG, CEP: 37500-903, Brazil

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ABSTRACT

Intensification and mechanization of agricultural activities have brought numerous benefits, among which, is the increase in food production. However, waste generation from animal has also increased tremendously. Creation of laying hens in cage system produces many wastes, which must be removed daily. This is important for the cage and farm environmental protection; which should be properly managed to ensure public health protection. In the pursuit for effective management, by using experimental data of a chicken farm in Itanhandu-MG, Brazil, the possible production at national level, of electric energy by anaerobic digesters from dejections collected in laying hens cages. In the present study, the GHG emissions impacts assessment, by tCO_{2eq}, in the COP21 from Paris 2015 context was evaluated using the Intergovernmental Panel on Climate Change (IPCC) methodology. For the economic viability of these wastes in energy generation, six scenarios of ten years were evaluated, all resulting from the combination between scenarios with and without funding, and with or without internal use of electrical power generated, but with real and presumed profit (in the framework of ANEEL nº. 482/2012 and nº.687/2015 resolutions) on micro-generation distribution. In all scenarios, energy was considered available to the Brazilian National Interconnected System (SIN), according to the 5th auction average price in 2015. The annual emissions avoided by methane burning and subsequent electricity generated was of 8.02 million of tCO_{2eq} and 38.4 thousands of tCO_{2eq}, respectively. Farms with more than 100,000 birds presented good probability in simulations of certainty, with regards to expected financial return. The most promising scenario was C6, tax modality of presumed profit, internal energy use, and sale of surplus energy (it would be also considered as credit on the next account), with financing of invested capital.

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1. Introduction

The use of clean and renewable energy sources must be encouraged, researched and developed. Among different possibilities, biomass and bioenergy presents as alternative energy source, since they contribute to national energy matrix and the goals for greenhouse gases (GHG) and pollutants emissions reduction. Specifically, the animal by-products, municipal solid waste, and agribusiness wastes usage represents a great opportunity for biogas generation and its use as an alternative energy source; thus, its conversion into electrical energy deserves to be researched and exploited.

Another important aspect that should be analyzed in relation to

* Corresponding author.
E-mail addresses: eruin.ribeiro@gmail.br (E.M. Ribeiro), remambeli@hotmail.com (R.M. Barros), tiago_unifei@hotmail.com (G.L. Tiago Filho), ivanfelipedeice@hotmail.com (I.F.S. dos Santos), lucanobre@yahoo.com.br (L.C. Sampaio), ticianevasco@gmail.com (T.V. Santos), ffbraga.silva@gmail.com (F.G.B. da Silva), ana-moni@uol.com.br (A.P.M. Silva), jvictor_rocha@yahoo.com.br (J.V.R. Freitas).

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agribusiness wastes and effluents is that which transmits to high organic load expressed in Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and nutrients such as nitrogen, phosphorus, potassium and calcium. If such elements were disposed without criteria in the environment, the quality of soil and water would be impacted, as they tend to accumulate in reservoirs and lakes, changing the limnological conditions; causing eutrophication, environmental and public health impacts. According to Cornejo and Wilkie [20], additional benefits of anaerobic digestion of waste includes the nutrients recovery from the bio-digested effluent, which may be used as biofertilizer and soil correction.

The residual biomass of poultry agribusiness usage can also decrease fossil fuels usage and GHG emissions, since residual biomass in decomposition emissions tend to be highly minimized.

Exploitation of energy from biogas is not only a potential source of income for farmers, but can also generate environmental benefits to the society as a whole. Carbon dioxide emissions can be reduced by sourcing energy from renewable sources, and effectively replacing electricity and other energy produced from fossil fuels Yiridoe et al. [52]. The electrical energy generation distributed throughout the rural area of Brazil contributes to the burden of \plying and energy production logistics in the whole country De Souza et al. [48].

Comparison carried out by Singh and Sooch [46] for Ludhiana city, Punjab (India) regarding the economic calculations showed that with increase in capacity, recovery period exponentially declined. De Souza et al. [48] and Avaci et al. [5] observed the economic viability of biogas electricity production from swine manure biodigestion; even without receiving carbon credits had an average of 4672 housed animals relating to a case study in São Miguel do Iguaçu - Paraná, Brazil. Avaci et al. [5] found that when carbon credits were considered, the production costs could decrease and profit would be generated, with a probable NPV (Net Present Value) increase.

Brown et al. [15] suggested that without incentive systems by policies, the entrepreneurship of biogas energy generation would not be economically feasible among the size-range farms studied. Among the investigated individual political schemes, the green-energy credit policy schemes are expected to generate the higher financial returns than those sharing costs regimes and low-interest loans. Resultantly, co-benefits and not market-schemes were recommended by Yiridoe et al. [52], as their results for energy production from biogas were financially feasible for small-size dairy farms (50-cows) and pigs (200-pigs) when co-benefits and not market schemes were evaluated in the CND$ 15,000 (or higher).

Cornejo and Wilkie [20] estimated that the total potential reduction of emissions from methane gas capture in anaerobic digestion of milk, pigs and cattle manure wastes to substitute the liquefied petroleum gas (LPG) by methane is 308 $GgCO_2eq$.

In the Brazilian potential point-of-view, which has 221, 86 million hens birds (IBGE, 2013) and produces on average 31 million kg of waste daily; this must be properly allocated in accordance with the Brazilian Federal Law 12.305/2010 (National Policy on Solid Waste, PNRS; Brazil, [10]), that was regulated by federal decree 7404/2010 Brazil, [11]).

Therefore, another relevant aspect referred to is the Greenhouse Gases (GHG) generation increment that has been the subject of increasing concern among the nation's leaders, society in general, national and international scientific community; and being the central theme of COP21 held in Paris 2015. Brazil has a National Policy on Climate Change (Law 12,187 of 29 December 2009; Brazil, [53,54]), and voluntary national commitment, which adopted GHG emissions mitigation, aimed at reducing between 36.1% and 38.9% of its emissions by 2020. This is taken as a basis for the second Brazilian inventory of anthropogenic emissions and removals of GHG emissions not controlled by the Montreal protocol. At COP21, Brazil undertook to reduce GHG emissions by 37% by 2025 below 2005 levels, and 43% in 2030. The countries signatories' nationally determined by each country have undertaken with contributions, the Intended Nationally Determined Contribution (INDCs). This document of 12 December 2015, proposes to keep the global average temperature increase below 2 °C above pre-industrial levels, and targets a value of 1.5 °C by the year 2100. The designed level by COP 21 is 55 $GtCO_{2eq}$ by2030, reducing emissions to 40 $GtCO_{2eq}$ or 1.5 °C above pre-industrial levels. In this way, it seeks to ensure deep reductions in net GHG emissions (United Nations, [49]).

Additionally, in the context of the Brazilian scenario, there is technical cooperation between the Brazilian Government, through the National Secretariat of Environmental Sanitation of the Ministry of Cities, and the German Government, through the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. The Brazil-Germany Project to Promote the Use of Biogas in Brazil, PROBIOGÁS, aims to increase the efficient use of biogas in basic sanitation, agricultural and agroindustrial initiatives to insert biogas and biomethane in the national energy matrix. Therefore,it aims to contribute to the reduction of emissions of GHG [59].

According to data available on electricity generation by the Brazilian National Electric Energy Agency (ANEEL, as acronyms in Portuguese), in Brazil in 2015, 21 types of thermal power plant (TPP) biogas were in operation, with a total power capacity of 78,231 kW (by biogas from Municipal Solid Waste, MSW), and 1804 kW (animals wastes). With respect to the granted power, there were 2 TPP, with capacity of 49.547 kW (MSW). There were 4 TPP on joint ventures with its construction not started, with authorized power capacity of 37,905 kW and 1 TPP from animal waste with 42 kW [3].

Resolutions were dependent on the power to be exploited by renewable energy source, as determined by ANEEL Resolution 482/2012 [2], to which undertakings from renewable sources (hydraulic, solar, wind, biomass or qualified cogeneration energy bases) can be benefited by mini and microdistributed generation. This resolution sets out the compensation system as an arrangement in which the active power injected by consuming unit with micro or mini-distributed generation is sold to the local distributor and then compensated by the consumption of electrical energy which activates for those same consumer units or for another consumer unit of the same ownership. On review of aforementioned resolution, the Normative Resolution nº. 687, of 24 November 2015, entered into force in March 2016, extends the benefits to enterprises such as biogas for up to 5 MW. This review also aims to reduce the barriers that still exist for micro and mini generators to distributor's network connections and target public increase. Furthermore, the energy excess injected by a consumer of Group A (high voltage) and used to compensate for the energy in another unit of the Group B (low voltage) should observe the relationship between the sum of the tariff components at $R\$.MWh^{-1}$ (TUSD and TE, as acronym in Portuguese), except for contiguous units (ANEEL [4]).

Barros et al. [7] evaluated a possible increase in energy generation from renewable resources, specifically from landfills by thermal biogas power plants. Their results further demonstrated that only cities with population greater than 200,000 inhabitants will this kind of energy be economically viable. Such values, however still represents a small percentage (0.00020% in 2010 and 0.44496–0.81042% in 2030) of the projected energy generation from residual fuels in accordance with the National Energy Balance (BEN, as acronym in Portuguese) plan created by the Brazilian Mines and Energy Ministry (MME, as acronym in Portuguese). Santos et al. [42] analyzed the economic viability and energetic potential of energy generation by biogas from anaerobic

wastewater treatment plants (WWTP) and their results indicated that economic viability would be theoretically possible, but only for cities with population greater than 300,000 inhabitants, and that energy potential could supply nearly 0.25% of the residual fuels according to the Brazilian Ministry of Science and Technology.

Based on these two aspects, Ribeiro et al. [39] evaluated the technical feasibility, the net converted power and electrical energy generated in order to find a solution to the energetic use of residual biomass of poultry sector (poultry farms on which laying hens are created). The obtained data by the authors (*op. cit.*) were related on the biogas volume and composition capable to be generated by residue mass, total solid (TS) mass and volatile solid (VS) mass for the case study in cages at Itanhandu - MG, Brazil. With this data, Ribeiro et al. [39] calculated the Brazilian biogas potential production and theoretical electric energy generation with the internal combustion engine usage. In this sense, impacts on GHG emissions avoided, in the $tCO_{2_{eq}}$ form, of the COP21 from Paris 2015, and the energy use economic viability of the abovementioned waste would be assessed. The present study has as its objective; the GHG emissions mitigation assessment, since it seeks for methane (CH_4) generation minimization, one of the main GHG emissions, in the solid organic waste management as those originated from the laying hens in Brazil, by its energy use, and its economic viability assessment.

2. Wastes from poultry farms in Brazil

Socioeconomic changes to the beginning of the 1970s until the first decade of the 21st century, relating to lifestyle habits, increasing energy consumption, prices changes and the search for new markets were tagged as responsible for the change in the productive structure in poultry creation segment. Areas of obvious to relates to the genetics and the animal nutrition, activities automation, and scale elevation; and the emergence of the term industrial poultry farming adopted from this period [8]. Deploying processes of total quality, price needs and competitive products and the search for external markets have made this segment work in an integrated way with the agribusiness activities. Resultantly, this segment became more directors oriented, minimizing the participation of family producers, and reinforcing the industrialization of this segment [16].

According to data from the Food Agricultural Organization (FAO) [24] in 2013, about 2.72 trillion units of hen eggs were produced in the world. According to the Brazilian Poultry Union, UBABEF, as acronym in Portuguese (UBABEF [51]), Brazil occupies the 7th position in the ranking of producing eggs countries and according to the municipal livestock survey of the Brazilian Institute of Geography and Statistics, IBGE, as acronym in Portuguese (IBGE [13]), approximately 221.8 million of laying hens were created in Brazil, with Brazilian southeast region being the largest producer.

The production systems used in most of enterprises are battery cages, with 350–450 cm^2.$poultry^{-1}$, that are 35–45 cm in height and tilt of 8° for eggs output by gravity effect until the collection tracks [35]. According to Medina Junior [30], modernization increases productivity, eases administration, drives deployment speed, maximum use of physical space, decreases ration wastes and the percentage of eggs not serviceable. For Santos et al. [41], the benefits of the creation of cages system present in more than 90% of poultry farms enterprises includes; the possibility of high animal concentration, diseases and parasites reduction, ammonia levels reduction, low dust dispersion and low cannibalism among the animals. However, the gain in production scale in these enterprises resultantly generates large amounts of solid wastes, which are generated on daily basis. Consequently, slurry management are performed daily or every two days by means of a mechanical conveyor for this type of cages, which removes the excrement and transports them to the gatherer chains [35].

Regarding the amount of waste per poultry, some authors quantified their amount of excrement, at 120 g.$poultry^{-1}$.day^{-1} [33], and 140 g g.$poultry^{-1}$.day^{-1} [34,45]. According to Fabbri et al. [22], there is the occurrence of some GHG emissions releasing in the case of large amounts of poultries manure accumulation and handling, such as carbon monoxide (CO), carbon dioxide (CO_2), ammonia (NH_3) and in smaller amount, methane (CH_4) and nitrous oxide (N_2O). Palhares and Kunz [35] affirm the risks to health and to the flock of poultries, when exposed for extended periods to these gases.

Itanhandu, in the state of Minas Gerais, has about 2% of the Brazilian stock of hens, and this city reaches 3rd place in laying hens farms. The aviaries in Itanhandu are all automated; it was the 1st Brazilian city in automatic and technological farms, with 75% of the export of fresh eggs from Brazil originating from Itanhandu. Although there are variations in the compositions of the hens rations, in general, rations are always composed of the same types of raw material, soybean meal, corn, sorghum, premix, calcium, and some particular protein. On any Brazilian farm, these raw materials are always used in compositions that may change according to the age and nutritional needs of each poultry stock [63]. The manure of laying hens for biodigestion experiment was obtained from an automated farm of Itanhandu-MG, with 2,000,000 heads of laying hens.

According to data of 2017 from the Brazilian Institute of Geography and Statistics, IBGE [64,65], from a total of 143,499,598 heads of laying hens, the State of Minas Gerais has an equivalent of 9.61%, and concerning the quantity of produced chicken eggs 799,328 (in thousand dozens), this state accounts for 9.88%. The Brazilian Southeast region, composed of the states of Minas Gerais, São Paulo, Rio de Janeiro, and Espírito Santo, has an equivalent of 47.38% of heads of laying hens and has 47.91% of the quantity of produced chicken eggs. If the Brazilian Southeast and South regions (states of Paraná, Rio Grande do Sul and Santa Catarina) were added, these numbers would be respectively, 70.97% and 69.92%.

The chicken production chain appears as one of the highlights of the Brazilian agro-business, with production and export records in 2016, moving more than US$15.85 billion per year and employing almost 3.5 million people in Brazil. The Brazilian poultry farmers invest in modern poultry and are betting on the use of technology, aiming at the modernization and automation of temperature control, lighting, humidity, and quantity of feed controlled by computer [62]. This includes family farmers working in the poultry-condominium system. Companies with tradition in the activity endorse projects offer raw material (chicks), inputs and technical assistance. In return, they gain in the standardization of the chicken chain [60]. According to Ferrarez [61], air conditioning costs can reach 22% of total costs from the chicken production for poultry famers. The temperate climate and the climatic variations of the country potentiate the high consumption of energy.

The anaerobic biodigestion of ejections from egg-producing poultry creation presents an attractive alternative and the recommended objectives by COP21 at Paris, in 2015 for waste management under the NPSW (Brazil, [10,11]) and NPCC [53,54]. The laying hens can generate 0.02 ($m^3.animal^{-1}.day^{-1}$) [37]. The dry chicken manure produces 0.43 m^3 of biogas per kg of solid [34], being that the dry residues of poultry farming has a generation potential of 1 m^3 of biogas for each 2.3 kg of manure. Ribeiro et al. [39] evaluated the anaerobic biodigestion at experimental scale of dejections of poultry-producing farm in Itanhandu-MG, Brazil that contains 2,000,000 birds distributed on three farms. Ribeiro et al. [39] carried out a biodigester construction for three experiments denominated E3, substrate characterization and quantification,

volume parameter (as biogas temperature and pressure) measurements, and the determination of methane potential generation by anaerobic digestion via quantification from these experimental measurements. These experiments were performed with a 3.3 L biodigester with 2.1 L coaxial annular gasometers; and three dilutions were made, with fractions of 6% (E3 6A; 6%TS), 9% (E3 9A; 9% TS), and 12% (E3 12A; 12%TS) of total solids in the substrate. Biodigesters were constructed based on the model proposed by Souza (2001), with some adaptations in accordance with Price and Cheremisinoff [38]; and the connection between the reactor and the gasometer of the biodigester was prepared based on the work of Parajuli [37]. Experiments used three gasometers with an internal area of 18,095 cm^2 (PCV tubes with a 5.0 cm of diameter) and a capacity of 2.1 L.

In the experiments, the WWTP sludge was used as inoculum in about 10% in relation to the mass of the laying hens manure, helping with the rapid departure of the biodigester. After two days of loading with the manure inoculated with WWTP sludge, biodigesters began to produce biogás. From the filling of the biodigester with only laying hens manure, it was observed that for 2 weeks there was no biogas production. After the addition of the inoculum, it was observed that in two days the digester began producing biogas. On a larger scale it would assist in the management of sludge wastes from Waste Water Treatment Plant (WWTP) since it could take advantage of a part of this environmental passive, besides reducing the volume of sludge disposed in landfills, which demonstrates the feasibility of such application. Most WWTPs are located in the South (22.81%) and Southeast (46.88%) regions; when considering these regions' added percentage, they correspond to 69.69% of the total of WWTP in Brazil [65], the most economically prosperous region and with the higher concentration of farms in the country.

The following influent substrate and effluent analyses (after biodigestion) were performed according American Public Health Association (APHA) recommendations using the Standard Methods for the Examination of Water and Wastewater, APHA [1]: Total solids (TS); Total volatile solids (TVS); Nitrogen; Total organic carbon (TOC); Chemical oxygen demand (COD); Biochemical oxygen demand (BOD); and pH measurements. From these experimental data use, the authors (*op. cit.*) calculated the theoretically available power in Brazil; from an Otto-cycle combustion engine and from the poultry posture stratification and whereas the conversion segment properties regarding the number of heads. In this sense, Ribeiro et al. [39] evaluated the theoretical potential in case that all posture aviaries in Brazil invested the poultry manures for energy purposes through the anaerobic biodigestion of such waste; and that it would be possible to aggregate to the Brazilian national electric matrix, an amount of 1642 TW h.$year^{-1}$.

However, this is an estimate from data obtained from biodigestion operated on laboratory scale. It was extrapolated to the total volume of the manure Brazilian productive chain because the high concentration of the laying hens farms in the South and Southeast Brazilian regions with similar climates and mechanization and modernization of these farms.

In the main producing areas of chicken eggs (69.92%) there is a strong hydrographic system available. Therefore, due to the concentration of laying egg producers in the South and Southeast regions of Brazil, with similarity regarding climatology, which affects the anaerobic digestion. There was the consideration in this work, which there could be an estimation of the potential of energy production from experimental data obtained in Itanhandu, Minas Gerais, to the Brazilian potential.

The Brazilian South and Southeast regions are more similar regarding climatological characteristics since they are included in tropical and subtropical regions (latitude between 25° and 35 °C). The Southeast region corresponds to a range of transitions between warm climates of low latitudes and climates of mesothermic medium latitudes, but its strongest characteristics are of tropical climate. The Southeast region and the Northern Paraná present high temperatures (annual average of 22 °C) and two defined seasons: a rainy season, which corresponds to the summer, and another dry season, which corresponds to the winter. The subtropical climate, which appears in the south of the state of São Paulo, in addition to the Southern region, is marked by well distributed rainfall throughout the year (average annual temperatures between 16 °C and 17 °C) and by a great thermal amplitude. The seasons of the year are commonly with high distinction, and the thermal amplitude is relatively very large. The rains, in almost all the Brazilian territory, are regularly distributed throughout the year.

According to the experiments of [63], the water consumption for the dilution of 1 kg of waste is approximately 4L. Thus, the average water consumption for the dilution of the worst-case waste is 3.25 L/s. This case consists of a huge farm, which waste production is 70 t/d, as described in Ref. [39]. The aforementioned discharge value is relatively low if we consider a country of a rich and prominent on the world scenario hydrography. In addition, water grants for insignificant uses in the country are conceded for uses up to 1 L/s, according to the National Water Agency (ANA) [66]. Therefore, it can be concluded even in the worst case, the water discharge for dilution is not much higher than that for insignificant uses. In the case of medium-sized or lower farms (or in general for farms with a waste generation of up to 20 t/day), the water discharge necessary for dilution fits into insignificant use. All these data demonstrate that the use of water for the dilution of waste for biodigestion in Brazil is feasible. Another aspect to be considered is the possibility of using treated sewage for dilution in biodigestion. Such practice would be advantageous in allowing the reduction of treated sewage discharge to be disposed in the water body and may become an interesting option for poultry farms. The domestic sewage treatment index in Brazil is 42.7% [72], although it is expected to increase in the coming years due to the universalization of sanitation.

3. Biogas purification processes

The biogas purification and cleaning process is designed to avoid damage to the combustion equipment and increasing its calorific value. The biogas with 65% methane has 22.353 kJ.$m^{-3}$of high heating value [41], being that the value commonly used is 23,000 kJ m^{-3} (equation (1)), and also being the high heating value of pure methane, dehumidified equal to 37,000 kJ m^{-3} [34].

$$LCV\left(kJ \cdot m^{-3}\right) = 90.67 x CH_4 \quad (1)$$

For Varnero et al. [50], the CO_2, H_2S, water vapor, nitrogen and oxygen removal increased the methane concentration by 95% or more, and the H_2S removal increased the engines and equipment (used for the electricity generation)lifetime. According to Kronos Ecochem [23] company, a simplified form of H_2S reduction from biogas occurs by biological route through the addition of 8–12% of air (atmospheric oxygen), injected into the gasometer just above the substrate. The atmospheric oxygen and hydrogen sulphide gas are oxidized and processed into sulfur by microorganisms present on the biogas surface. The sulfur returns to the substrate in elemental form, which in part supports the oxidation reaction and residual part is discarded beside the final effluent. The choice of the purification and cleaning process is related to the type of biogas end-use. Purification procedures can be divided into several steps.

The most important part of the process of purification is the

removal of CO_2, in addition to water vapor and H_2S removal [29,43]. According to Lora and Venturini [28], the presence of substances in the non-combustible biogas, hinder the burning process, making it less effective. There is still the presence of gases such as N_2, H_2 and H_2S, the latter being corrosive. Table 1 shows the main technologies used for the biogas purification.

4. Biogas conversion to electrical energy

There are several technologies for efficient biogas conversion. The conversion efficiency is the process that transforms one type of energy in another. In the case of biogas, chemical energy contained in the molecules is converted into mechanical energy, by a process of controlled combustion. This mechanical energy activates a generator that converts into electrical energy. The gas turbines and Otto-Cycle internal combustion engines are the most widely used technologies for this type of energy conversion [18]. The following forms are known for the biogas conversion in electrical energy: internal alternative combustion engines (ICE), indirectly through boilers, *Stirling* engines and advanced techniques in micro turbines [6,9,40].

For using boilers with the biogas, some adjustments need to be made to use, and there must be control of the biogas humidity, adequate flowing control, and control of the flame inside the boiler. The *Stirling* engine is an alternative with an efficiency of about 40–45%, which requires external source of heat, has low noise and high operational safety. It has about 25,000 h of service-life, but there are few tested varieties and few data reliability. The turbines, for using with poor gases, require adaptations in the combustion chamber and gas prior cleaning before burning it. They have easy installation plan, and use their own burning heat to heat the air in the combustion chamber, which increases its efficiency [40]. The turbines'characteristics are: good capacity to operate with gas from biomass, constant gas flowing requirements, 30–33% of efficiency, low gases emissions, and advantages in cogeneration with residual heat usage and modularity possibility [17].

ICE are considered as robust machines and are indicated for operation with biogas, because they have reduced costs and can be used for small and medium sized electrical power demands of hundreds of kilowatts and up to dozens of Megawatt. ICE have a median efficiency between 22 and 33% of conversion, and their efficiency sharply decreases as methane (CH_4) decreases below to 50% (v/v) [40]. The combustion engines can operate by Otto-cycle or Diesel-cycle. In the diesel cycle, fuel is injected in the combustion chamber, the piston then compresses the air in the chamber, it spontaneously occurs beginning the burning until it reaches a high enough temperature. In the Otto Cycle, piston compresses an air and fuel mixing in the combustion chamber, and a spark causes the compressed fluid combustion [44]. For the electrical energy generation, diesel cycle and by gas engines are competitive, due to their high thermal efficiency in total or partial load, independent of local environmental conditions such as temperature, pressure and humidity, with the possibility of residual heat utilization for cogeneration [26]. Due to the fact that Brazil is a hot climate country, the heating of biodigesters does not pose major problems for the technical and economic feasibility of the project. The combustion exhaust gases themselves in the energy conversion technology can be used for this heating. In addition, if electricity were used for such heating, Ribeiro et al. [67] calculated the energy consumption to maintain the biodigester at 36 °C. The authors obtained as a result a value of only 2.3% of the annual electricity production from the biogas produced.

5. Methodology

5.1. Carbon emissions avoided by burning and electricity generated

Table 2 shows the available energy which could be generated per year, concerning each rural grouping property as studied by Mendes [32], and that could be available for sale, use or both, as calculated by Ribeiro et al. [39]. The calculations of Ribeiro et al. [39] were carried out based on biogas generation experiments from the anaerobic digestion of laying hens in the city of Itanhandu (Minas Gerais state). There were characterization tests of this substrate before and after biodigestion, as well as biogas analysis and quantification. This is a city with more than 2,000,000 birds among the various laying hen farms and is located in the most economically developed region of the country (Southeast Region). Ribeiro et al. [39] obtained biogas production at laboratory-scale biodigesters and applied these data to calculate biogas and electricity generation potential. The authors considered that biodigesters would be used for the biodigestion of poultry manure throughout the production chain. Obviously, the composition of the poultry manure varies in different regions of the country, which

Table 1
Technologies for removal of impurities of biogas.

Impurity	Technology	Material Used
Water	Adsorption	General silica molecular sieve Alumina
	Absorption	Ethylene Glycol −6.7 °C Selexol Temperature Cooling to 2 °C
Hydrocarbons	Adsorption	Activated Carbon
	Absorption	Light oil Ethylene Glycol Selexol Temperature −6.7 °C to - 33.9 °C
	Combination	Cooling ethylene glycol and adsorption in activated Carbon
CO2 and H2S	Absorption	Organic solvents Solexol Fluorine Rectisol Alkaline salts Potassium hot and hot inhibited Alcanolâminas Mono-, di and trietanolâminas Diglicolamina - CR Ucarsol solvent
	Adsorption	Molecular Sieve Activated Carbon
	The membranes	Hollow fiber
Siloxines	Adsorption	Activated Carbon

Source: Lora et al. [28].

Table 2
Potential energy generation classified by properties and total potential. Source: [31,39].

Property	Amount	Energy(MWh.year^{-1}) potentially generated by property	Total energy (MWh/year^{-1}) potentially generated
Huge	30	3715	111,437
Great	242	2229	539,356
Medium	267	743	198,358
Small	322	351	119,609
Minimum	780	223	173,842
Family	1813	74	134,690
Total			1,277,293

could cause a regional variation of the biogas production and the energy potential. However, considering that: the huge number of laying hens in this city; the studied poultry farm is one of the largest in the country, which ration differs little from other large farms; and the fact that there is concentration of laying farms in the southeast region, with similar climatic conditions, it can be considered that studies of poultry manure as presented by Ribeiro et al. [39] would be representative of the whole country. In addition, the calculations from the experiments of Ribeiro et al. [39] approximated those calculated from the theoretical data of the São Paulo sanitation company (CETESB) (Table 3), which contributes to validation of the methodology applied by the authors and the respective energetic potential obtained. Theoretically, there is the possibility of generating 1.27 TW h.year^{-1} of electrical energy, which corresponds to 0.22% of what was produced in Brazil in 2013 when compared with data from Brazilian energy research company [21].

Taking into account the GHG emissions, expressed in CO_2-equivalent (CO_{2eq}), in function of the complete stoichiometric biogas combustion, the combustion chamber of the ICE, in addition to exceeding the burners and by electricity generated; the avoided emissions calculation (in tons of CO_{2eq}) followed the methodology of the Intergovernmental Panel on Climate Change (IPCC) [55], according to equation (2).

$$E_{CO_{2_{eq}}} = E_{CO_2} + (21xE_{CH_4}) + (310xE_{N_2O}) + \sum_{i=1}^{n}(PAGx\mathrm{HCF}_i) \quad (2)$$

where:

$E_{CO_{2_{eq}}}$ = total equivalent carbon dioxide emissions (t);
E_{CO_2} = total carbon dioxide emissions (t);
21 = 100-year's methane Global Warming Potential;

Table 3
Biogas production comparison and net power calculation. Source [31,32,39].

Properties groups by Sizing[a]	Experiment (E3 6A)[b]		Effluent software[b] v. 1.0 CETESB (2006) Usage	
	CH4 (m^3)	Power (MW)	CH4 (m^3)	Power (MW)
Huge	4763	0.606	4524	0.614
Great	2858	0.363	2711	0.368
Medium	953	0.121	900	0.122
Small	476	0.061	449	0.061
Minimum	286	0.036	265	0.036
Family	95	0.012	88.5	0.012

Note.
[a] Mendes [32];
[b] Ribeiro [31] and Ribeiro et al. [39].

E_{CH_4} = methane total emissions (t);
310 = 100-year's nitrous oxide Global Warming Potential.
E_{N_2O} = nitrous oxide total emissions (t);
PAG = type "I" HFC refrigerant Global Warming Potential; and
HCF_i = type "i" HFC refrigerant total emissions.

For the avoided emissions calculated by electricity generated, the average value of emissions (in tCO_{2eq}) was taken into account, by considering the electric generation in the energy matrix in the Brazilian National Interconnected System (NIS), which was inventoried at 0,1355 $t_{CO_{2_{eq}}}.MWh^{-1}$ in 2014, according to the Brazilian Ministry of Science and Technology (MCT/Brazil [14]).

5.2. Economic viability

For the economic viability analysis, a computational simulation was carried out, using the effluents (1.0) *software* from the Brazilian's São Paulo State Environmental Sanitation Company (CETESB, as acronym in Portuguese; [56]). For such, the corresponding costs on investments needed for each useful power unit calculated (Table 3), the following equipment to be used in the anaerobic biodigestion process was considered: tanks and gasometers, piping, compressors, filters of CO_2/H_2S, burner and ICE (Table 4). IGP DP updated the equipment costs in accordance with the Central Bank of Brazil at 72.79%. Additionally, for digesters tanks sizing 30-days of HRT was used, with a fat content of 6% of TS in the substrate, which represented the addition of 80% water.

The period of time considered as a scenario for the cost simulation was 10 years, taking into account that energy would be available to the NIS, according to the average price of the new-energy A5auction of Energy Trading Chamber (CCEE, as acronym in Portuguese), of April 30, 2015, by the average value of R$ 278,45 per MWh [19]. Taking into account the search for economic viability for the electric energy generation in aviaries of posture, simulations were carried out on actual profit taxation schemes and presumed profit. According to Thymos Energy Company, in Prandini et al. [36], the taxes incidence on this type of renewable energy source is shown in Table 5.

For Real profit, the sector charges were considered, with changes in the calculation and aliquot of taxes IRPJ with aliquot of 25% and CSLL with aliquot of 9%, all focusing on the profit. The following scenarios were assessed in the simulation:

- C1: real profit without funding, with the total sale of energy;
- C2: real profit with funding, with the total sale of energy;
- C3: presumed profit without funding, with the total sale of energy;
- C4: presumed profit with financing with the total sale of energy;
- C5: presumed profit without financing with internal use and sale of additional power(which also would work as energy credits in the next account), in the context of regulatory Resolutions Aneel Resolution No. 482/2012 [2] and n° 687 [4]; and
- C6: presumed profit with financing, internal use and sale of additional power in the sphere of regulatory Resolutions Aneel Resolution No. 482/2012 [2] and no 687 [4].

For the scenarios C5 and C6 the following data were considered:

- Energy consumption per batch of 100 thousand birds/year equal to 76,560 MW h according to publication of Embrapa as preconized by Girotto [57];
- Cost of megawatt hour for rural areas classification B2 set at R$ 514.25 MW h, according to data from the Electricity Company of Minas Gerais (CEMIG) [58], the month of May 2015,red flag, included PIS, Cofins and ICMS.

Table 4
Estimated investments (in 1000R$) by property sizing. Source: adapted from effluent 1.0 software (CETESB [56] and corrected according to the Central Bank of Brazil (BACEN), by IGP-DP.

Property	Tank/Gasometer	System/Collection	Flare	H_2S/CO2 Filters	Compressor	Engine Generator	Work eng. Connection	Total
Huge	1629	22	17	612	175	1139	407	4001
Great	977	22	17	368	105	684	246	2419
Medium	326	22	17	112	32	208	81	798
Small	163	22	17	122	35	227	71	657
Minimume	101	22	17	36	10	67	28	281
Family	33	22	17	14	3	22	12	122

Table 5
Taxes and aliquots incidence - presumed profit. Source: Prandini et al. [36].

Description Tax	Aliquot	Basis of calculation
Legal Personal Income Tax (IRPJ)	15%	8% Revenue
Social Contribution Net Profit (CSLL)	9%	12% Revenue
Social Integration Program (PIS)	0.65%	Recipe
Contribution to Social Security Financing (Cofins)	3%	Recipe
Description Sectorial Charges		
Rate Surveillance Services in Electrical Power (TFSEE)	0.50%	Recipe
CCEE contribution rate	Exemption biomass encouraged	
Transmission System Usage Rate/Distribution (TUST/TUSD)	Exemption biomass encouraged	
Rate of Research and Development (R&D)	Exemption biomass encouraged	

The fixed and variable costs related to purification systems, motor generator group, burner, and anaerobic digestion tanks maintenance were fixed at 23.7% of gross revenue, similar percentage to the one used by Lindemeyer [25] in a case study in the state of Santa Catarina. According to Lora and Haddad [27], the variable costs related to ICE and generator group stand between 0.007 and 0.015 US$.kWh^{-1}, appropriate value in the range of the abovementioned percentage. The assets depreciation have followed the items I and II of the SRF Normative Instruction n^{o}. 162, of December 31, 1998 of Federal Revenue (Brazil [12]). For the discounted cash flow calculation, which is the basis for the financial analysis of the simulations, the following modelwas used,as shown in equations (3)–(8).

$$RBVE = (EG \times PE) + (EC \times TE) \quad (3)$$

where:

RBVE = energy sold gross revenues (R$);
EG = energy generated per year (MWh.year^{-1});
PE = energy price (R$.MWh^{-1});
EC = consumed energy (MWh.year^{-1}); and
TE = rural energy tariff (R$.MWh^{-1}).

$$RLVE = RBVE - IP \quad (4)$$

where:

IP = proportional tax (R$).

$$LB = RLVE - CT - ES \quad (5)$$

where:

LB = Gross Profit (R$);
CT = total costs (fixed and variable costs) (R$); and
ES = sectorial charges of energy generation (R$).

$$LAIR = LB - DT - Dp - DJ \quad (6)$$

where:

LAIR = Profit before income tax (R$);
DT = total costs (fixed and variable costs);
Dp = depreciation of assets (R$); and
DJ = interest expenses (R$).

$$LL = LAIR - IRPJ - CSLL \quad (7)$$

where:

LL = Net Income (R$) IRPJ = Income Tax on the profits (R$); and
CSLL = Social Contribution on Net Income (R$).

$$FCD = LL + Dp + AD - In + LFn + VR \quad (8)$$

where:

FCD = discounted cash flow (R$);
Dp = depreciation of assets (R$);
AD = amortization of debts (R$);
In = Investments (R$);
LFn = release of financing (R$); and
VR = residual value of the investment (R$).

Analysis of the project financial viability was made by using of the economic engineering concepts, by Net Present Value (NPV) and Internal Rate of Return (IRR) calculations; taking into account the minimum attractiveness rate (TMA, as acronym in Portuguese) of 15%, with financing of 75% of the capital invested in fostering banks by the constant depreciation system (SAC, as acronym in Portuguese). Also, for this calculations, with an interest rate of 4.0% per year, by the National Bank for Economic and Social Development (BNDES, as acronym in Portuguese), into the *Inovagro* program context, it were considered as a no grace period. NPV was calculated based on the cash flows of the present value discount brought, according to equation (9). The IRR is the discount rate that equals zero (equation (10)), the cash flows discounted at present value.

$$NPV = \sum_{t=0}^{n} \frac{FCDt}{(1+i)^t} \quad (9)$$

$$IRR = \sum_{T=0}^{n} \frac{FCDn}{(1+i)^n} = 0 \quad (10)$$

For investments in energy recovery of waste, in which net power

and power available showed viability, i.e. VPL >0 and TIR > TMA, a sensitivity analysis was made, using the Monte Carlo simulation. In order to minimize the uncertainties on those values found that do not meet expectations of VPL and IRR simulated, variations in the net power generated, price of the energy sold, percentage of total costs on the revenue and the capacity factor used in the simulations were carried out; in addition to a sensitivity analysis to variations of some parameters which may compromise the results. Table 6 shows the varied parameters in each simulation.

6. Results and analysis

6.1. In tCO2eq avoided emissions

Table 7 presents the calculated data on emissions (in avoided tCO_{2eq}) for each type of property and the simulated property groups, i.e., a total of 8.023.074 $tCO_{2_{eq}}.year^{-1}$, which was avoided by the CH_4 stoichiometric complete combustion in ICE and burners, and the 38.439 $tCO_{2_{eq}}.year^{-1}$, avoided by the electrical energy generation in NIS.

In accordance with the EPE (2014), the generated emissions ($intCO_{2_{eq}}$) produced $115 kgCO_2.MWh^{-1}$ electricity in NIS during the year 2013. Taking into account that the energy generation in the year was of 570,02 TW h, emissions avoided by CH_4 stoichiometric combustion, for electricity generation in the follow-up studied, could reduce 9.1% the CO_2 emissions from the national electric matrix for that year.

6.2. Economic viability

Tables 8 and 9 shows the NPV and IRR values as calculated in each net power in accordance with the taxes arrangements (real or presumed profit) and the presence or absence of financing. It is worth mentioning that in the two simulations corresponding to the scenarios C5 and C6, the generated energy use to meet the energy needs of the joint ventures themselves was taken into consideration, as preconized by ANEEL Normative Resolutions nº. 482/2012 [2] and nº 687/2015 [4], with the surplus sale to the concessionaire (as credits in the next bill).

According to Table 8, without financing, investments in the taxation regime of real profit with use of own capital, the IRR value was well below the minimum attractiveness rate (TMA), of 15% and values were all negative for all NPV simulated powers; therefore, it should be disregarded as it does not offer adequate financial return. Figs. 1 and 2 shows more significant IRR and NPV values in accordance with the tax and financing system.

By observing the graph of Figs. 1 and 2 and Table 8, it is verified that better returns, with IRR and NPV largely occurred in the regime of presumed profit with financing, internal use of electric energy generated and sale of surplus for the concessionaire. However, regarding the power of 61 kW, variation and depression of the IRR and NPV values occurred.This is explained in function of investments and thus, submits a variation and increase of 134% in relation to the previous power, with an increase in revenues of 69%. The increase in revenue was much lower than the investment. Nevertheless, the IRR and NPV for this power band, in the presumed profit modality with internal use of energy and the sale of surplus, presents an obvious economic viability. Table 9 shows the returning time (payback) in years, for each investment in generation.

It can be observed from Table 9 that the returning time values were lower in the modalities of presumed profit without funding. This is explained by the absence of financing, which elevated the callback time beyond the capital term of payment, which in these simulations are 10 years. However, the returning time can not be the only indicator for the analysis of the investments feasibility. In the simulation, better returns IRR > TMA and NPV>0 presented greater returning time values.

Taking into account the risks and uncertainties related to the generation of electrical energy, with the variation of the parameters of potential generation of biogas, from Ribeiro et al. [39], and the Monte Carlo simulation, all the studied powers carried out showed viability in tributary modality presumed profit with financing, internal use and marketing of the surplus, the following probabilities of results that reached the expected values are presented:

- 606 kW, probability of NPV>0 and IRR > TMA were in 57% and 62% respectively;
- 363 kW, probability of NPV>0 and IRR > TMA were in 77% and 78% respectively;
- 121 kW, probability of NPV>0 and IRR > TMA were 66% for both;
- 61 kW, probability of NPV>0 and IRR > TMA were 0.6% and 0.5% respectively;
- 36 kW, probability of NPV>0 and IRR > TMA were set at 5% for both;
- 12 kW, probability of NPV>0 and IRR > TMA were 8% and 9% respectively.

Table 7
Emission in $tCO_{2_{eq}}.year^{-1}$ by methane burning and generated electricity.

Ownership	$tCO_{2_{eq}}.year^{-1}$			
	By Property (burning)	Total (burning)	By Property (electricity)	Total (electricity)
Huge	23,332.39	699,971.57	647.13	19,413.95
Great	13,999.43	3,387,862.40	388.28	11,648.37
Media	4666.48	1,245,949.39	129.43	3882.79
Small	2333.24	751,302.82	64.71	1941.40
Minimum	1399.94	1,091,955.65	38.83	1164.84
Family	466.65	846,032.30	12.94	388.28
	Total	8,023,074.13	Total	38,439.62

Table 6
Analysis of sensitivity to the variation of some critical parameters.

Installed Power (kW)	Parameter to be varied	Distribution type	Variation (%)		
			Minimum	Average	Maximum
606 to 121	The net installed power	Triangular	- 20,00	- 10.00	1.00
	Energy fare	Triangular	- 50,00	−25.00	1.00
	Total cost	Triangular	- 10.00	1.00	10.00
	Capacity Factor	Triangular	- 10,00	1.00	10.00
61 to 36	The net installed power	Triangular	- 11,00	−6,50	1.00
	Energy fare	Triangular	- 25.00	−20,00	1.00
	Total cost	Triangular	- 2,50	1.00	2.50
	Capacity Factor	Triangular	5.00	2.50	1.00

Table 8
Comparison among NPV and IRR actual profit scheme *versus* presumed profit and assumed with energy use.

Taxation	Financing	Parameters	Power (kW)					
			606	363	121	61	36	12
Real profit	Not	IRR (%)	12.40%	12,10%	12,30%	6.20%	10.00%	6.90%
		NPV (R$)	−574735	−375319	−117372	−291554	−74680	−50202
	Yes	IRR (%)	22.70%	22.30%	22.70%	9,10%	4,10%	10.50%
		NPV (R$)	660919	371756	129080	−88648	−28789	−12524
Presumed profit	Not	IRR (%)	16.80%	17.04%	12.70%	9,30%	12.90%	3.50%
		NPV (R$)	399859	277551	112051	−198214	−34412	−48555
	Yes	IRR (%)	34,10%	34.90%	35,40%	13.80%	19.30%	16.10%
		NPV (R$)	1544951	968873	330677	−18217	13081	3024
Presumed profit Internal Use	Not	IRR (%)	17.50%	17.50%	18,20%	9.90%	13.60%	10.90%
		NPV (R$)	567648	347840	145534	−177281	−22059	−27011
	Yes	IRR (%)	36,40%	36.42%	08 a.m. at 37.70%	15.20%	24.00%	17.30%
		NPV (R$)	1712741	1037270	364160	3502	54926	Ext. 6413

Table 9
Time of return to the investments in each power.

Taxation	Real profit		Presumed profit		Presumed profit Internal Use	
Financing.	Not	Yes	Not	Yes	Not	Yes
Power (kW)	Returning time	Returning time	Returning time	Returning time	Returning time	Returning time
606	7.3	13.6	5.7	10.9	5.5	10.4
363	12.1	13.7	5.6	10.6	5.5	10.4
121	7.3	13.6	5.5	10.5	5.2	10.1
61	11.2	20.0	8.0	17.1	8.6	16.4
36	8.5	15.8	7.2	12.4	6.8	13.1
12	10.6	19.7	8.3	15.0	8.1	15.4

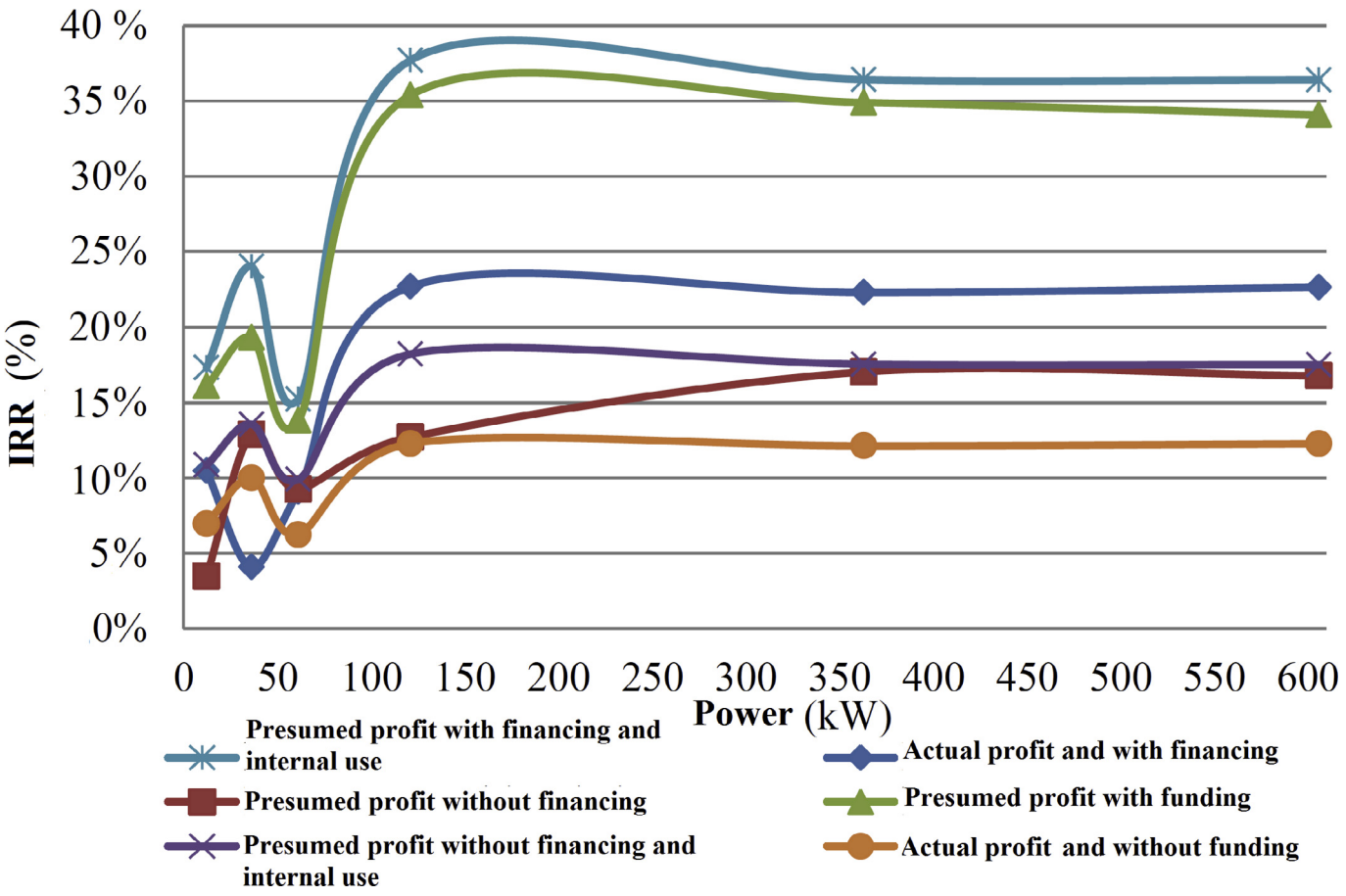

Fig. 1. IRR by net power and tax modality.

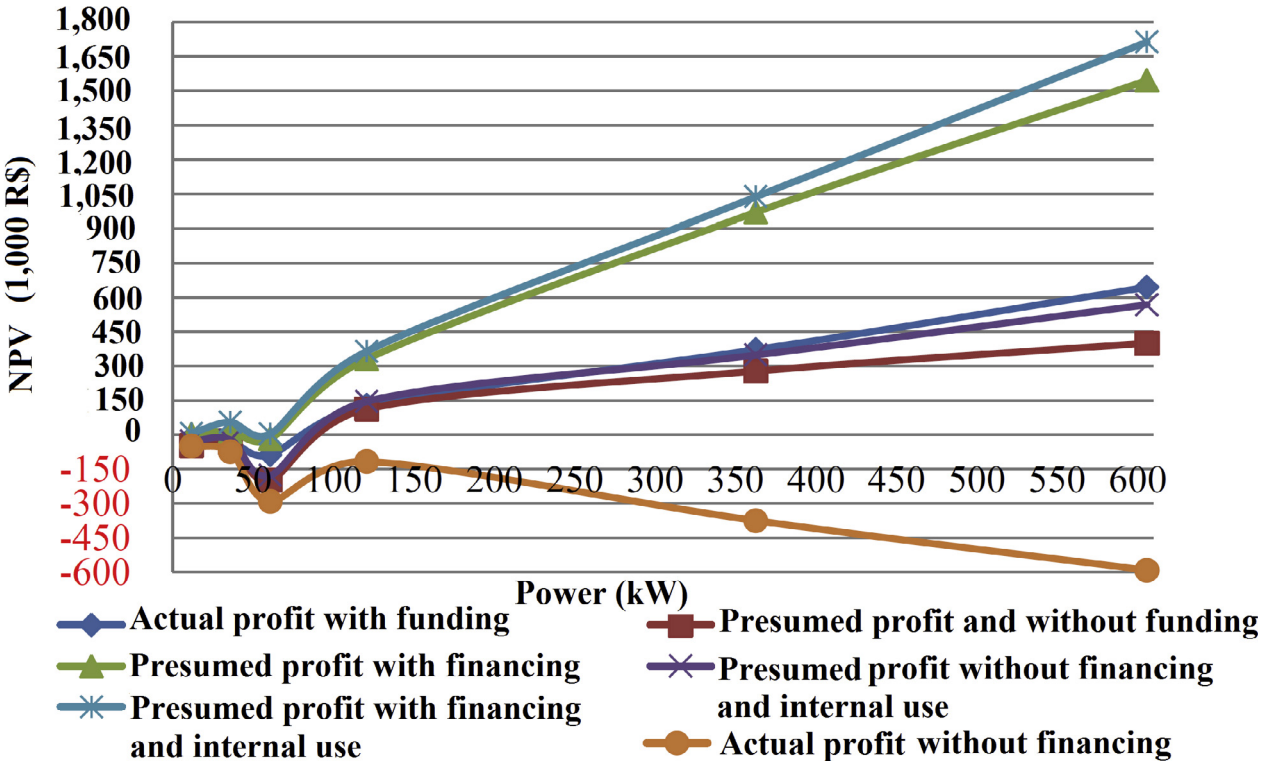

Fig. 2. NPV by net power and tax modality.

Therefore, taking into account the Brazilian ACR market, in each properties group simulated, with the average tariffs practice in the last A5 auction of the CCEE [18] for biomass and incentives sources, the use of biomass energy-producing poultry residual for the generation of electric energy would be economically feasible. However, in order to minimize the risks and uncertainties, poultry farms with more than 100,000 birds were considered to present good probability of certainty regarding their expected return. This is explained as these investments admits higher variation in net power generated, energy tariffs, operation costs and capacity factor as they presented better returns with larger IRR and NPV.

Brazil has a high biogas potential not yet exploited (which can reach an installed electrical power of 7 GW) and several recent initiatives have been taken to develop the biogas market in Brazil [68]. These initiatives include: i) PROBIOGAS project [59], in partnership with the German development agency GIZ, which was aimed at identifying barriers for biogas development, proposing solutions and financing the dissemination of knowledge between countries; ii) Creation of the Brazilian Association of Biogas and Methane in 2014 (ABBM, in Portuguese), with the active participation of companies interested in the sector (AABM, 2014) [69]; iii) Biomethane from landfills and wastewater treatment plants was regulated by the Brazilian National Agency for Natural Gas and Biofuels (ANP, in Portuguese) by Resolution n°. 685 [73] of June 29, 2017. Furthermore, Art. 16 of this resolution changes the Biomethane specification table of products and wastes from commercial and agroforestry, of the ANP Technical Regulation n°. 1/2015 contained in the ANP Resolution n°. 8 [74] of February 2, 2015; and iv) Recently, it was enacted the law creating the Brazilian National Biofuels Policy by law no. 13576/2017 [75] and the Ministry of Mines and Energy has set up a program called “Renovabio”, aimed at stimulating bioenergy in Brazil, by the creation of the carbon reduction mandate for fuel sold by the distributors, which was fulfilled by the purchase of Emission Reduction Certificates (ERCs). The certificate was issued to ethanol, biodiesel and biogas plants that were successful in the certification process. The price of the biodiesel produced will vary depending on the level of production and the efficiency of carbon reduction (MME, 2016 [70]). It is estimated that the investment for biogas production in Brazil is 50 billion of Reais by 2030 [71]. In this context, the development of the biogas market in Brazil can also leverage the sanitation sector and the treatment of agricultural wastes, as is the case of the wastes from chicken farms in the country.

7. Conclusion

The Posture cages grouped by poultry head number were reared as: enormous (500 thousand), large (300 thousand), medium (100 thousand), small (50 thousand), minimum (30 thousand) and family (10 thousand). Also, from the mass calculation of waste produced per day, the respective power and available energy were calculated by Ribeiro et al. [63]. The power values found were of 606 kW, 363 kW, 121 kW, 61 kW, 36 kW, and 12 kW. Considering the capacity factor (CF) of 70%, the available energies calculated were of 3715 MW h.year^{-1}, 2229 MW h.year^{-1}, 743 MW h.year^{-1}, 371 MW h.year^{-1}, 223 MWh.year^{-1}, and 74 MWh.year^{-1}, respectively [39]. If all aviaries of posture used this waste for energy purposes, it would be possible to aggregate to the national electric matrix a total of 1277 TW h.year^{-1}; this would represent a 0.22% of energy produced in Brazil as at 2013. The avoided annual emissions by methane burning and generated electricity would be of 8.02 million $tCO_{2_{eq}}$ and 38.4 billion $tCO_{2_{eq}}$ respectively, which would represent a reduction of approximately 9% of GHG emissions in the Brazilian energy matrix on NIS.

Simulations on economic viability were carried out in six different scenarios, C1 to C6, with and without public funding. The most promising scenario was C6, presumed profit tax modality, internal energy use and sale of surplus(it would work also as credit

on the next account), with financing of capital invested. In this scenario, for all sizes of aviaries properties; the simulations presented economic viability with IRR higher than the TMA values and positive NPV value. Furthermore, the ventures could benefit from the ANEEL compensation system given by Resolutions nº. 482/2012 [2] and nº 687/2015 [4], with energy sold to the local distributor and then compensated with the consumption of electrical energy activities of that same consumer unit or of another consumer unit of the same ownership, with the recent inclusion of ventures up to 5 MW. Results regarding the sizing group of the poultry farms were: enormous 36.4% and R$ 1,639,376 respectively; large 35.9% and R$ 1,019,204 respectively; sized 37.7% and R$ 364,160 respectively; small: 15.2% and R$ 3502 respectively; minimum 24% and R$ 54,926 respectively and family farms 17.3% and R$ 6413 respectively. In addition a Monte Carlo simulation was carried out, varying some tariff parameters, produced energy, capacity factor and percentage of total costs (operation and maintenance), aiming to reduce the risks of IRR be less that TMA and NPV less than zero. Probabilities were: 606 kW, probability of NPV>0 and IRR > TMA was in 57% and 62%; 363 kW, probability of NPV>0 and IRR > TMA was in 77% and 78%; 121 kW, probability of NPV>0 and IRR > TMA was 66% for both; 61 kW, probability of NPV>0 and IRR > TMA was 0.6% and 0.5%; 36 kW, probability of NPV>0 and IRR > TMA was set at 5% for both, respectively. Risks related to not to achieving positive results with IRR and NPV levels are lower for aviaries that have between 100 thousand to 500 thousand of hens heads than others.

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